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An assessment of postural sway in ballet dancers during first position, relevé and sauté with accelerometers.

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Abstract

Classical ballet is a performance art where unintentional and uncontrolled movement degrades the aesthetic. Vertical torso movement can induce body tilt. Postural sway was measured in pre-professional ballet dancers when performing simple vertical movements. 47 pre-professional dancers (5 males and 42 females, mean age in years = 19.2, SD = ± 1.3) on a full time undergraduate dance program were asked to stand in first position and perform a demi-plié, a relevé and a sauté. These movements were performed in a continuous cycle undertaken 15 consecutive times. The first 5 cycles were undertaken as practice. The second set of 5 cycles were recorded with the arms held in Bras bas, with the final 5 having the arms held in fifth position (rounded arms placed above the head). Accelerometers were attached to the lumbar spine (L4) and thoracic spine (T1-T2). The tilt during the demi-plié prior to the sauté and relevé increased significantly for both arm positions. The male participants preparative angle change was much larger than the female participants ($p = 0.07$). No significant angle change was observed between the Bras bas and arms in fifth position for the sauté but the change is significant for the relevé ($p = 0.007$). Exaggerated forward tilt is undesirable both aesthetically and biomechanically. Small accelerometer sensors on the spine can allow self-monitoring practice of these basic classical ballet movements.

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Keywords: accelerometer; classical dance; demi-plié, first position, position, sway, Bras bas, jumps;

1. Introduction

Body fixed accelerometers have become a recent addition in sport and dance due to their light-weight and compact size. They can be placed on the body without causing restriction to the individual and allows instantaneous feedback to the coach or individual. Swimming [1], cricket [2], hockey [3] and ballet [4] have applied this technology to assess skill level and improve performance.

Classical ballet is an art form that requires the performer to maintain a strong posture whilst completing difficult steps. In classical ballet postural sway can be addressed in the terms of increased pelvic tilt, and the increased movement of the thoracic spine. Aesthetically this is unappealing as it suggests the performer is compensating in order to perform the required step. A study into postural sway surmised that pre-professional classical ballet dancers who had a higher skillset had less postural sway than those who were less skillful [4]. This suggests that they required less relocation of segments of the body in respect to the centre of mass and to perform the skill [5].

The usual method of measuring postural sway or angular displacement of the body involves a biomechanical lab and expensive equipment such as Vicon® and ground reaction plates. Smith et al., [6] used trunk kinematics and ground reaction force plates to

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show how dancers coordinate their lumbar and thoracic spine separately and relative to one another in order to control their sauté (vertical jump) when arms were placed in fifth position. This in turn helps to address weaknesses that would normally be missed by coaching staff. However, this type of analysis requires experience and is time consuming. The wealthiest ballet companies rarely take advantage of this equipment due to the necessary time constraints already imposed on ballet companies, it therefore, stands to reason that this technology is not exploited within vocational ballet schools. Thus, utilizing the small size and low cost of accelerometers may identify the amplitude of segmental motion in the lumbar and thoracic spine, both separately and relative to each other, helping to aid in performance improvements, as well as those recovering from injury. Thiel [4] identified that accelerometers could be used to ascertain postural sway in simple a first position demi-plié. A demi-plié is the basis for the beginning of a sauté (jump). It follows that postural sway in first position may be more evident when performing a sauté and should be increased when the arms are in fifth position (both arms raised) due to the relocation of the centre of mass from the base of support [7].

Westblad et al [8] reported a significant difference between the eccentric and concentric muscle contraction in ballet dancers. Excessive sway impedes eccentric landing qualities which have repercussions for continuous jumps, decreasing performance. This sway could be accentuated by fatigue. Pappa et al. [9] suggested that fatigue causes an increased activity of rectus femoris, with a specific increase found within females. Lin et al. [10] speculated that ballet dancers had a larger anterior/posterior sway when compared to medial/lateral sway due to lateral rotation from the hips. They also reported that there was a significant difference in anterior/posterior sway in those who had suffered a lower leg injury. This supported the finding by Leanderson et al [11], who state that ballet dancers who had suffered from a sprained ankle had a noticeable loss of postural control. However, Lin et al. [10] only compared injured to non-injured dancers. With no prior measurements before the injury, one might conclude that poor postural control may have led to the sprained ankle, as postural sway has been shown to be significantly higher in less skillful pre-professional classical ballet dancers [4].

Ballet is judged by its aesthetic look. Having quantitative information allows for a greater understanding of how a dancer is progressing and giving sufficient feedback in order to address technique, help in identifying fatigue, and help in aiding in rehabilitation. It may also help to eradicate favoritism, prejudice and preconceived ideas about the individual performer. Therefore, this study was to extend on the work already carried out by Thiel [4] with the use of accelerometers in ballet. The aim of the study was to determine if accelerometers can identify postural sway in basic progressive ballet positions. The hypothesis was that acceleration measurements could identify increased postural sway during basic progression in ballet positions: first position in demi-plié, demi-plié prior to relevé, a demi-plié prior to sauté with arms in Bras and fifth position. The null hypothesis is that there was no difference in postural sway during the movements.

2. Experimental Method

Forty seven (5 males and 42 females, mean age in years = 19.2, SD = 1.3) were recruited for this study from an undergraduate dance program (age range 17 – 24 yrs). The students had gained admission on this course via an audition process. The participants were verbally informed of the study protocol and were made aware that participation was voluntary and that they could withdraw at any time. They were also informed of possible risks and possible harm. Ethical approval was received from Griffith University (ENG/14/13/HREC).

The data collection took place at the dance studios at Queensland University of Technology with the mirrors blacked out. This was done to ensure that the participants didn't alter their eye alignment and therefore their head position and orientation. The participants were required to wear their class uniform and flat ballet shoes.

Upon commencing of the trial participants were weighed and their height taken. Participants completed a background survey reporting their age, current level of training, classical ballet experience in years and current training load. The participants reported weekly training of 35.7 ± 4.1 hours per week. The participants had warmed up prior to measurements and testing.

Two inertial sensors, provided by SABEL Sense [12] were used during this experiment. The inertial sensors were tri-axial accelerometers (size L; 55mm x W; 30mm x H; 13mm, weight 23g) and could be wirelessly activated through the SABEL Sense software. One sensor was secured to the Lumbar spine (L4) using a Velcro waist band and another sensor was attached to the thoracic spine (T1-T2) using medical tape (see Fig. 1). Each participant was represented with a number that was attached to the chest with safety pins. This allowed for later identification during analysis and checking from the video record.

Participants were allocated to one of three markers on the floor. This is done for the purpose of the video camera (25 f/s) and safety. The participants were asked to stand still in first position (a lateral rotation from the hips with heels together) with their arms placed in Bras bas (arms held off the thighs in a rounded position). The sensor orientation was recorded and formed the reference angle for tilts which occurred during movement. Deviations from zero degree occur because of imperfect positioning on the spine. The participants performed a demi-plié (knee bend with heels remaining on the ground, Fig 1a & 1b), a relevé (starts from straight leg into demi-plié finishing with straight legs on tip toes also known as demi-pointe, Fig. 1c & 1d) and finally a sauté (vertical jump initiated by a demi-plié, Fig. 1e & 1f). These were performed in a continuous cycle 15 consecutive times to an audio beat count and demonstrated by a professional dance instructor. The first 5 cycles were undertaken as practice. The second set of 5 cycles was recorded with the arms held in Bras bas, with the final 5 having the arms held in fifth position (rounded arms placed above the head). These are progressive steps that are common within ballet training and as warmup exercises before a performance.

A video camera was used to validate the accelerometer analysis qualitatively and to identify participants during data analysis. Upon completion of the data collection the acceleration data and video sections were transferred to computer. Calibration of the accelerometer data was undertaken using the SABEL Sense software, resulting in the data being expressed in terms of gravitational acceleration $g = 9.8 \text{ ms}^{-1}$. Matlab was used in order to process the data. The acceleration data analysed was collected at the base of the demi-plié for each of the 5 cycles for the three demi-pliés, basic, prior to relevé and prior to sauté and converted to angle relative to horizontal ($0g$). The average angle was used in the statistical analysis using Microsoft Excel 2010. A two-tail t-test was performed between the sacrum and the thoracic angles, in both Bras bas and fifth position with statistical values set at $P=0.05$.

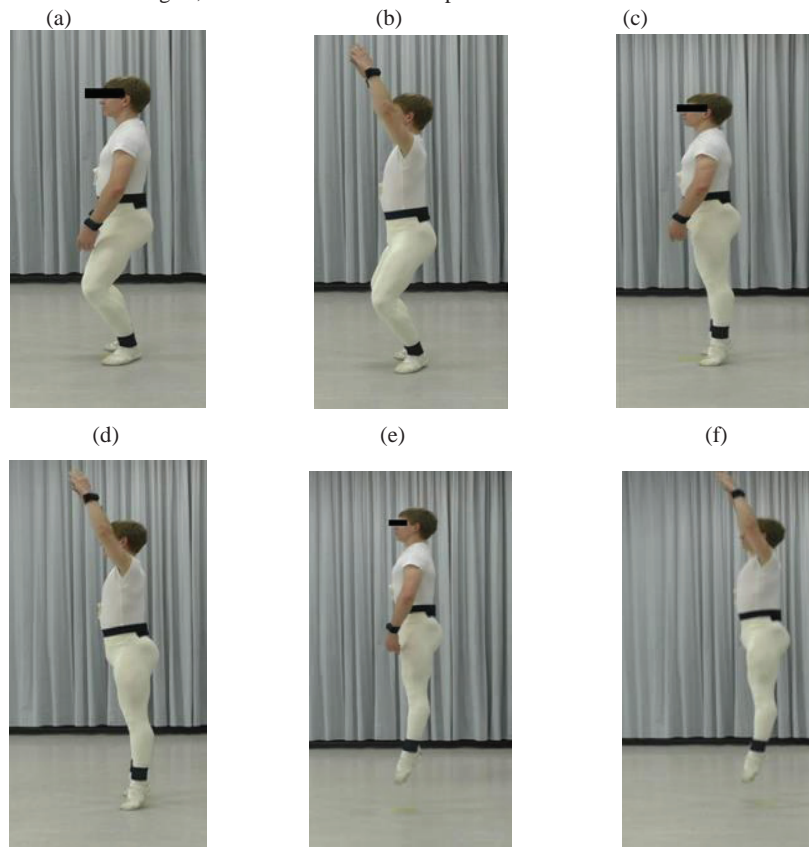


Fig. 1. Vertical dance movements used in the study. The anterior posterior tilt angle was measured with an accelerometer on the thoracic spine (not visible) and at the sacrum using a Velcro waist band (a) Plié in 1st with arms held in Bras bas; (b) Plié in 1st with arms held in fifth position; (c) Relevé on demi-point arms held in Bras bas position; (d) Relevé on demi-point arms held in fifth position; (e) Sauté arms held in Bras bas; (f) Sauté arms held in fifth position.

3. Results and Discussion

Table 1 shows the age, height, weight and experience distribution in the participants. All fit within the normal BMI and lie in the age range of high school graduates ($\cong 19$ years) who have directly transitioned from high school to university studies.

Table 1: Mean and standard deviation of age, height, weight and ballet experience ($n=47$).

	Age (Years)	Height (cm)	Weight (kg)	Experience (years)
Males ($n=5$)	19.0 \pm 1.4	179.7 \pm 3.73	73.7 \pm 7.9	5.2 \pm 4.1
Females ($n=42$)	19.3 \pm 1.3	166.1 \pm 6.13	59.4 \pm 6.8	13.5 \pm 3.3

The anterior posterior accelerometer profile from the two spinal positions was converted to angle relative to the vertical (the horizontal plane is zero degrees) assuming the major component of acceleration was the static gravitational component only. This is axis the most sensitive to anterior posterior body sway. Dynamic accelerations are caused by high speed movement and dominate

the static measurements and so yield incorrect vertical angles. During the demi-plié immediately before the sauté, the participants prepare for an explosive vertical force resulting in significant errors in the static acceleration derived angles.

A typical result (female participant 12) is shown in Fig. 2a and 2b for the Bras bas and fifth position respectively. For the Bras bas position the initial angle was approximately -19° and -22° for the sacrum and spine respectively when the arms. The two sensors are almost identically aligned at -19° with the arms in fifth position. Clearly the tilt of the thoracic sensor has been reduced and matches the sacrum sensor. For female participant 27, the initial sensor orientations for Bras bas are 0° and -10° for the sacrum and thoracic sensors respectively, and -5° and -10° for the arms in fifth position. The change of arms from Bras bas to fifth position has resulted in change in the thoracic sensor orientation.

Each of the three movements can be identified as minimum angle values. In Fig. 2a, the demi-plié angle is at time 86.1 s, the relevé at 89 s, and the jump at 92 s (over-range due to dynamic acceleration). Of major significance to this study is the angle at the original position (first position), the angle changes in the demi-plié leading up to the three movements, and the maximum change in this preparatory angle. The change was calculated by subtracting the minimum value during the demi-plié from the initial stationary value in first position.

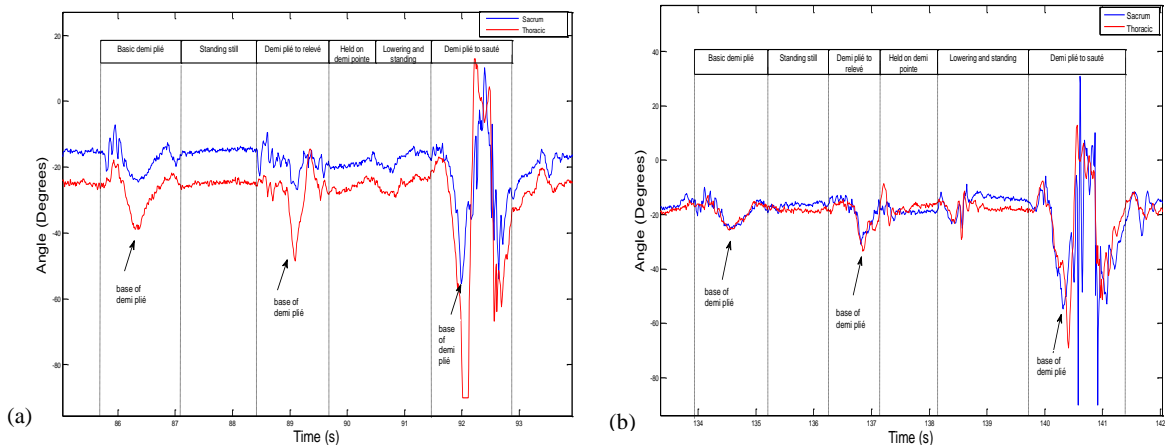


Fig. 2. Anterior posterior angular displacement of accelerometers located on the sacrum (L4) (blue line) and thoracic (T1-T2) (red line) with the arms held (a) in Bras bas position; (b) in fifth position. The thoracic and sacrum movements are very in phase and similar. (Female participant 12, experience 17 years).

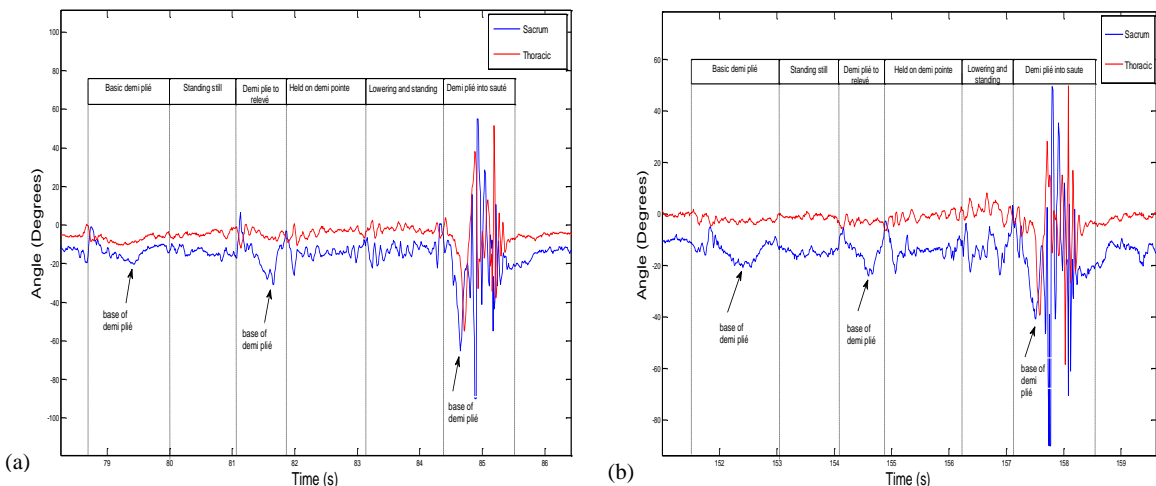


Fig. 3. Anterior posterior angular displacement of accelerometers located on the sacrum (L4) and thoracic (T1-T2) with the arms held (a) in Bras bas position; (b) in fifth position. There is very little thoracic movement for this participant with the major position adjustment coming from the lower spine. (Female participant 27, experience 3 years).

Most participants (88%) showed increased forward tilt angles at both spinal positions through during the basic demi-plié, and demi-plié's prior to the relevé and sauté movements with arms in the Bras bas position. With arms in fifth position, all female participants and 4 from 5 males showed the change in the demi-pliés an increased forward tilt. The results are summarized in Table 2.

A comparison between the basic demi-plié, and the demi-plié's prior to the relevé and sauté with the two different arm positions (Bras bas and fifth position) demonstrated that when the arms were held in fifth position angular tilt is less than when the arms are in Bras bas for all participants. This suggest that when the arms are in fifth position the torso becomes significantly more stable either because of enhanced concentration in preparation for a more difficult set of movements or this is a more stable biomechanical position.

The thoracic angle during the demi-plié prior to the relevé was larger in the male participants (mean value -9.4°) compared to the females (-4.5°) for both arm positions and both thoracic and sacrum sensors. The male participants increased their tilt more than the female participants. For the female participants the difference between the demi-plié mean angle prior to relevé (-13.0°) was significantly different ($p = 0.03$) to the demi-plié alone (-8.2°). The male participants demi-plié angles were -14.2° and -4.8° respectively and the change was even more significant ($p = 0.003$).

Table 2: The cumulative results from the 10 measured demi-plié movements are shown as mean values and standard deviation of the angular change in participants for the three movements, both sensor positions and both arm positions. Note that a negative value indicates a tilt forward. The demi-plié angles before the sauté are an over-estimate due to a significant contribution from the dynamic acceleration.

	Demi-plié(degrees)	Demi-plié before Relevé (degrees)	Demi-plié before Sauté (degrees)	Sensor location	Arm position
Male	-4.0 ± 8.0	-10.4 ± 2.6	-44.2 ± 33.5	Thoracic	Bras bas
Female	-5.6 ± 4.7	-6.1 ± 8.8	-31.1 ± 34.4	Thoracic	Bras bas
Males	-6.3 ± 3.9	-15.7 ± 9.5	-25.5 ± 14.3	Sacrum	Bras bas
Female	-9.9 ± 8.8	-17.5 ± 11.1	-35.4 ± 12.3	Sacrum	Bras bas
Male	-2.2 ± 6.7	-18.0 ± 18.5	-43.9 ± 36.3	Thoracic	fifth position
Female	-8.2 ± 8.8	-13.6 ± 8.7	-34.7 ± 13.1	Thoracic	fifth position
Male	-6.8 ± 5.0	-12.8 ± 6.1	-26.1 ± 15.8	Sacrum	fifth position
Female	-9.1 ± 5.6	-14.9 ± 7.9	-34.2 ± 10.0	Sacrum	fifth position

For the sensor at the sacrum, there is no significant difference between the female demi-plié using arms in Bras bas and fifth position ($p = 0.34$), but there a significant change between the relevé using different arm positions ($p = 0.007$). The male participants showed no significant trend ($p = 0.21$ and $p = 0.23$). This might be consequence of less experience by the male participants (male experience 5.2 ± 4.1 years, female experience 13.5 ± 3.3 years), with arms in fifth position. For the thoracic sensor location, the female participants showed some significant difference between the arm positions ($p = 0.64$) for the demi-plié while the male participants showed a stronger difference ($p = 0.23$). The relevé showed very significant differences for female and male participants ($p < 0.001$, $p = 0.48$ respectively).

4. Conclusions and Further Work

This investigation demonstrates that two accelerometers located on the upper and lower spine can be used to assess angle changes in the sagittal plane. In particular, the change in posture leading up to and during the three movements (demi-plié, relevé and sautés) for two different arm positions (Bras bas and fifth position) was quantified. The angle of change for sensors in both positions on the spine from demi-plié alone to demi-plié leading to the relevé was significant (male $p = 0.003$ and female $p = 0.03$) and the demi-plié before the sauté was impossible to determine accurately because of the excessive dynamic component of the acceleration. These measures are of significant interest to individuals who wish to practice without feedback from a trained human observer.

Change in the segment control, at the lumbar (sacrum) and thoracic spine, is caused by the body's momentum to appropriately position the centre of mass over the feet. Due to the arms being held in Bras bas and fifth position the participants used variable trunk control patterns to aid in completing the step [6]. This is why greater angles of change occurred during the progression of the step. Knowing how the body coordinates the trunk to perform a demi-plié in these progressive steps may help in the acquisition of the skill. It could also be argued that due to the required lateral rotation needed to stand in first position and then maintain this lateral rotation during demi-plié, caused increased lower back lordosis (tilt/postural sway in lumbar spine) compensating through the thoracic spine [15]. The changes in moment that are required to increase the propulsion that are needed to perform the relevé and sauté, cause the participants to adjust segment alignment in hopes of keeping the centre of mass over the feet [16]. Identifying the change in the thoracic sensor orientation, when the arms moved from Bras bas to fifth position, may be due to the participant's inability to control the shoulder movement whilst maintaining core control. Knowing this identifies an area that could then be addressed by the coach for further improvement. Therefore, identifying how an individual is performing a demi-plié is fundamental

to developing in their progression in ballet and helping to identify areas of weakness, serving to reduce the onset of possible acute and chronic injury.

Prior research has indicated that less postural sway can reduce the likelihood ankle injuries [14 in addition to improving dance performance aesthetically. The core stability of dancers is also important in the Royal Academy of Dance specification designated as the “correct posture and weight placement” of pliés (page 16, [13]). During these simple exercises, the lead up to and the completion of these movements can be monitored. During the trials, acceleration measurements were made on the both wrists and ankles. This data has yet to be reviewed and presents a significant opportunity for further analysis.

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